

Project Number: P11252

TOP CAT

Alexandra Peruzzini / EE - Project Manager

Duncan Topley / Electrical Engineer

Obinna Ukachukwu / Electrical Engineer

ABSTRACT

The primary goal of the Top Cat project was to design, build, and prove concept of a short range device used to prevent domestic outdoor cats from fighting. A retired Electrical Engineering Professor from Rochester Institute of Technology, Mr. David Perlman, facilitated the project with specific product requirements. Professor George Slack provided the team with guidance. In order to achieve the project objective, a team of engineers was initially divided into Software Design, Hardware Design, and Antenna Design sub-teams. The chosen device was a cat collar that would pulse a stimulus (sound) that would annoy the cat if it was in range of another. During the initial stage of the project, it was obvious that the bulk of the project would be based on software design. That being said, algorithms were created individually and debugged as a group. The algorithms were designed to use an LED as the stimulus to prove the feasibility of the project. The speaker was then implemented later on. The final stage of the project is to prove the concept of a short range alert device using a pre-developed kit. The device should begin to alert and annoy the cats once they are in range. The closer the cats get, the more often the annoying stimulus is emitted. In this paper, the algorithm design, possible fabrication, testing processes and results will be described in detail.

INTRODUCTION

Outdoor cats are more prone to fighting. Owners are not always able to keep an eye on their cat as it roams freely outside. Today's technology offers many

useful products to aid in the design of short-range devices which will deter cats from a fight. Figure 1 shows a depiction of the chosen range for the project. Figure 2 shows a possible representation of the collar once it is produced.

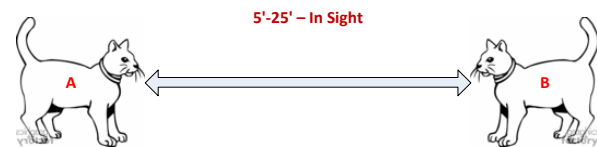


Fig. 1 In Sight Distance for Cat Collars

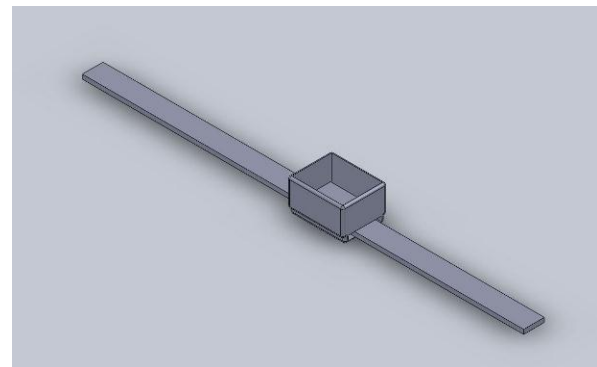


Fig. 2 CAD representation of possible collar design (including casing)

Microcontrollers have been a growing technology since they emerged on the market in the 1970's. They are a small computer on one integrated circuit. This chip includes a processing core, memory and input/output programmable peripherals. Microcontrollers are designed for an embedded application which allows devices to be automatically controlled. The primary purpose of the design is to attract students to digital technologies and related courses taught at RIT. Another goal is to create a feasible short-range platform for future senior design projects or graduate students to build from and improve upon.

In the first phase of the project, an idea was conceived to alert both humans and cats that there is a

possibility of feline hostility. Sonar, GPS and RF technologies were looked into for concepts. Sonar was looked into first since sonar is very precise when determining distance. Sonar used reflected sound waves to see if objects are nearby. The problem with this technology was the risk of the sound waves reflecting off of a random object (not the other cat). GPS was the next to be researched, since similarly to Sonar, the technology is very precise for determining distance. Unfortunately, the implementation of GPS devices and available IC's are expensive and difficult to find. RF was lastly researched. This technology has limited issues when transmitting and receiving in the line of sight and can be rather inexpensive to implement. However, RF is not the best technology to use when determining distance.



Fig. 3 Texas Instruments CC430 Chip

NOMENCLATURE

BER – Bit Error Rate; the number of bit errors caused by noise, interference, distortion or bit synchronization divided by the total number of bits transferred over a specific time interval.

RSSI – Received Signal Strength Indicator; Indication of the power level being received by the antenna. The higher the RSSI number the stronger the signal.

CAD - computer aided design; use of computer technology to aid in the design and production of a product. Typical CAD packages are 3D solid surface modelers.

Watchdog – A computer hardware or software timer that triggers a system to reset.

LOS – Line of Sight

DAC – Digital to Analog Converter

Development Kit - A pre-designed kit used for testing before creating a final product.

PCB – Printed Circuit Board

Debugging – a methodical process used to minimize the number of defects in a computer program.

RF – Radio Frequency.

Sonar – Sound Navigation and Ranging

GPS – Global Positioning System

dB(m) – Decibel; logarithmic unit that indicates the ratio of a quantity relative to a reference level. The 'm' in dBm indicates that the reference is one milliwatt.

IC – Integrated Circuit

Packet – Formatted unit of data transmitted from one device and received by another.

TI – Texas Instruments

TX – Transmit

RX – Receive

Duty Cycle – The time the system spends in an active state.

OVERVIEW

In order to prove concept for a functional collar that meets the project's needs and requirements, three distinct groups were formed and functions were assigned. The Software group was responsible for configuring registers and creating the algorithms needed to receive and transmit a signal. The hardware group designed the DAC and speaker setup which would be controlled by an algorithm created by the Software group. The last group was the Antenna Design group. Tasks performed by the Antenna Design group included the research and design of a functional antenna that would fit the specifications of the project. The requirements of the Antenna group and Hardware group were not as time consuming as those of the Software group. Therefore, after the deliverables were met for the Antenna and Hardware groups, the team members merged with the Software group to aid in the process. At the conclusion of the project, all three groups were combine deliverables and produce a single functioning proof of concept.

SOFTWARE DEVELOPMENT

The primary objective of the Software group was to design and upload algorithms to the Development Kit. Since there were many different concepts to include into the algorithms, the Software group was made up of the entire team. Everyone was to work on their part of the algorithm and then the code would be combined later on. There were a few major thoughts that needed to be included in the algorithms.

Algorithm Stages:

Since the software development of this project is the majority of the work, the software was split up among the team to cover the most important needs. The code was written in stages since it would be easier to split the code among the group members.

The first stage is to have the boards successfully transmit and receive. Once they are working properly, the code must be manipulated to have the speaker sound every time it transmits. The next stage would be taking the RSSI data that the chip has, and convert it to a dBm value. This dBm value will roughly

determine the distance of the board. The code should set the boards to transmit faster and faster (making the speaker beep faster and faster) as the boards get closer to one other. Lastly, the boards must reset after a specified amount of time, if the cats decide to fight regardless. The algorithms created should begin when the cats are “in sight” at 25’. Figure 4 shows the System Flowchart created for this project.

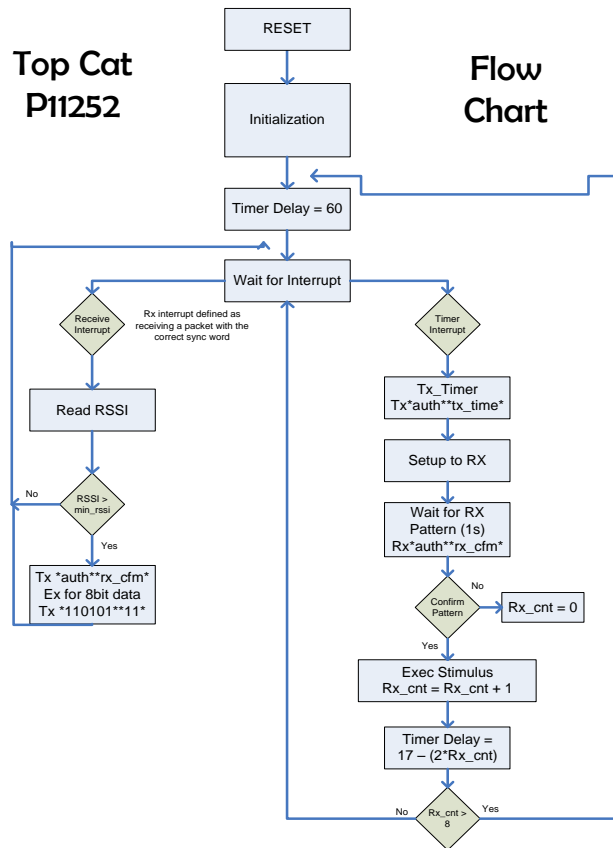


Fig. 4 System Flowchart

Figure 4 is the original algorithm design for the project. The flow chart shows that we utilized two main interrupts, a timer interrupt and a receive interrupt. The timer interrupt translates into a transmit. After the transmit, the device switches modes to receive to be able to communicate with the other device. For every successful receive, a count is started to decrease the amount of time between timer interrupts.

Algorithm Design:

The final code is a combination of code developed specifically for this project and code found through testing many sample codes. To efficiently create a working code, it was created in parts and tested as it was written. This would lead to fewer issues and less debugging the end.

The first part was to create a simple code to transmit from board A to board B. This will prove the

functionality of the board as well as create an understanding as to which registers need to be initiated. The built-in LED was then added into the code to light up every time the board transmits.

The next part was to take the information gathered about programming the Development Kits in the first part, and apply it to creating a code which will transmit based on data gathered from the RSSI. This indicator takes the signal strength and converts it into a value of dBm. Theoretically, the closer the boards are, the larger (or more positive) the dBm values of the received packet. The code will check the RSSI value on a timed increment. Figure 5 shows the code for taking the raw input data for RSSI and converting it to a meaningful unit, dBm. This conversion is a critical part of the design because every calculation uses dBm as the primary unit of measurement.

```

rssi_dec = ReadSingleReg(0x34);

if (rssi_dec >= 128)
    rssi_dBm = (long)((long)(rssi_dec - 256) / 2) - rssi_offset; //converts RSSI to dBm
else
    rssi_dBm = (rssi_dec / 2) - rssi_offset;
    
```

Fig. 5 Raw RSSI Data conversion to dBm

The RSSI idea used in the step above was kept but instead of having the boards transmit faster and faster based on a time increment, have them increase transmission based on the current RSSI value.

```

/***** Design Parameters Start *****/
signed int rssi_threshold = -50;
int rssi_distance_delta = 3; //amount of dbm required to increase stimulus
int delta_beep = 8000; //amount of change in beep length
int transmit_cnt_max = 300;
/***** Design Parameters End *****/
    
```

Fig. 6 Critical Code Parameters

Using the RSSI value (dBm), the lowest signal strength which will still produce a stimulus can be determined. This parameter is the RSSI threshold. This critical design parameter is shown in Figure 6. At the collar range limit, 25 feet, the relative dBm value was determined to be -50 dBm. Setting this up as a design parameter, is allows the user flexibility to increase or decrease the range of the device. The stimulus is required to increase as the cats move closer. The rssi_distance_delta parameter was created to allow flexibility to what the device considers a change. In this case, every 3 dBm, the stimulus increase or decreases. The delta_beep is the amount of time per 3 dBm change. The time value is a repeating loop; therefore not directly related to seconds. The last critical parameter is the transmit_cnt_max. This is a redundancy check to make sure the device resets after 300 consecutive transmits. This is a fail-safe so if any unknowns happen with the device, it will reset automatically.

The final stage was to implement the actual DAC and speaker. Since the CC430 chip only outputs in digital format and the speaker requires analog, a DAC was used to convert. More code was added that not only flashes the LED every time the boards transmit, but also turns the port high that the DAC and speaker are connected to. This way, the speaker should beep simultaneous to the LED flash.



Fig. 9 Connection to Upload Code

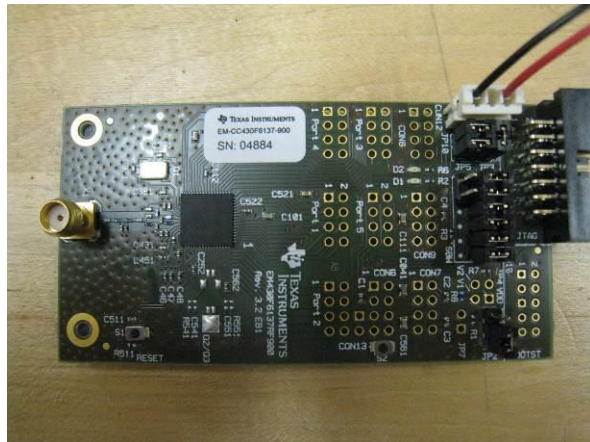


Fig. 7 Development Kit – Without Antenna

Figure 7 shows a close-up view of one Development Board. Each board was individually programmed using a USB to J-TAG connector. Figure 8 shows the two boards and antennas that came with TI’s Development Kit. The boards are programmed to transmit automatically as well as transmit by a push-button found on each board.



Fig. 8 Both Boards of the Development Kit with Antennas

Once the code was written and debugged using Code Composer (a software provided by TI), the USB to J-TAG connector was used to connect the board to the computer, Figure 9. Once the code was uploaded to each board, the boards could then be disconnected and tested.

Algorithm Tests (Feasibility):

Feasibility assessment of the proposed design concept was completed using RFStudio which is a TI program that allows the user to test their devices under a variable of different parameters. To perform this test, the boards were connected to two separate portable computers where one was set to transmit and the other to receive. One hundred packets were sent per 1 foot increments from 5’ to 25’. The data was collected for both an indoor and outdoor test. Since RF is not typically used to determine distance, this test had to be performed to see if this idea was even practical.

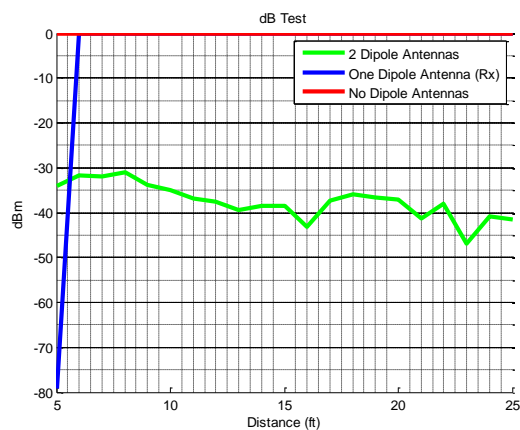


Fig. 10 Indoor Feasibility Test Results

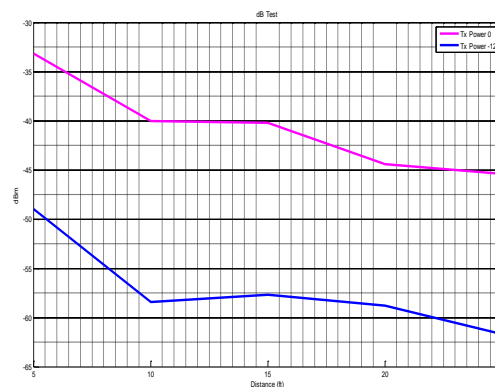


Fig. 11 Outdoor Feasibility Test Results

As seen in Figure 10, there was no transmit success without antennas and there was little success with one antenna. With one antenna, packets were

only received within the first 5 feet. The main purpose of this test was to see the dBm results when transmitting packets with both antennas. Our goal was to see a change (drop in dBm as the distance increased). As seen above, there was a small decrease in dBm consistent for the first 15ft, and then the values just seemed to bounce around in a non-linear fashion.

Figure 11 shows two lines for each test with a different transmit power. As noticed, they follow the same pattern. This proves that the data collected outside, with little interference can be rather consistent. Since the cats will be outdoors, it is safe to assume that it is feasible to approximately determine distance using RF.

POSSIBLE FABRICATION

To fabricate this product, there are many items to take into consideration. A practical PCB antenna design is crucial for the project since the battery and size of PCB can be determined after the antenna has been designed. The speaker must suffice and be small enough to fit on a cat collar. The collar cannot be too heavy, or else it can be unsafe for a cat.

Before the project was determined to be a proof of concept, some PCB antennas were looked into for practical designs. Figure 12 shows the comparison of a PCB versus a Chip antenna. When designing an antenna, there are some important formulas that are necessary for valid design.

Antenna Types	Pros	Cons
PCB Antenna	<ul style="list-style-type: none"> • Very low cost • Good Performance at >868 MHz • Small size at high frequencies • Standard design antennas widely available 	<ul style="list-style-type: none"> • Difficult to design small and efficient PCB antennas at <433 MHz • Potentially large size at low frequencies
Chip Antenna	<ul style="list-style-type: none"> • Small size • Short TTM since purchasing antenna solution 	<ul style="list-style-type: none"> • Medium performance • Medium cost

Fig. 12 PCB versus Chip Antenna

$$Z_0 = Z_L \tag{1}$$

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{2}$$

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{3}$$

$$S_{11} = 20 \log(\Gamma) \tag{4}$$

$$0 \text{ dBm} = 2.14 \text{ dBi} \tag{5}$$

$$\lambda = \frac{30000}{f \text{ (MHz)}} \tag{6}$$

When choosing the antenna for this project, there are some fundamental equations we need to understand. Equation 1 is the Max Power Transfer theorem. We want our source resistance to equal the load resistance. Equation 2 is the Complex Reflection Coefficient. If Γ is equal to 0, then the antenna is perfectly matched. The Voltage Standing Wave Ratio is Equation 3 and Equation 4 is Return Loss (dB). These equations are used to determine how well the antenna is matched. The antenna is well matched if the VSWR is around 1.5. Many suppliers reference their designs to an ideal Isotropic antenna; Equation 5 is the conversion factor. Equation 6 determines the wavelength of the antenna.

There are some considerations that should be made for antenna performance (per App Note AN058). The antenna placement makes a difference on the performance. When using $\frac{\lambda}{4}$ wavelength antennas, there must be a ground plane. There can also be undesired magnetic fields on the PCB or objects that disrupt the LOS which can also affect the performance. Antenna gain, bandwidth and radiation efficiency all effect performance as well.

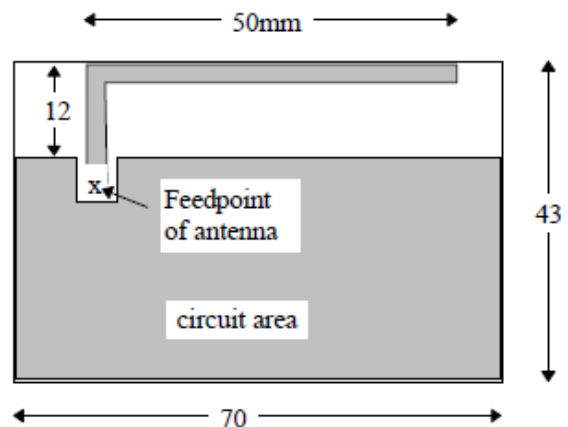


Fig.13 Printed Open Stub at 916.5 MHz

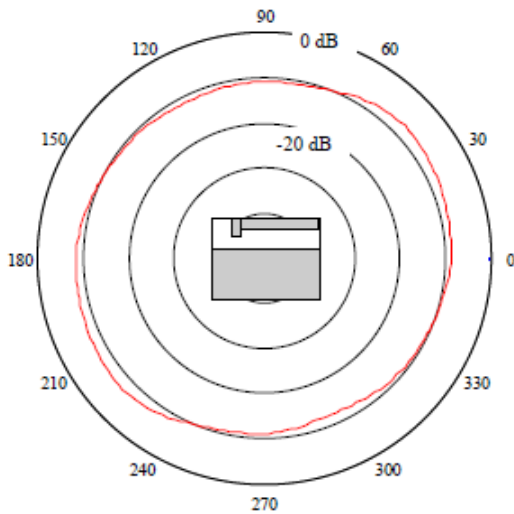


Fig.14 Radiation Pattern of Printed Open Stub Antenna

Figure 13 shows a printed open stub design at 916.5 MHz, which is the frequency at which the proof of concept was made. This is a plausible idea for a PCB design. Figure 14 shows the radiation pattern for this specific open stub antenna.

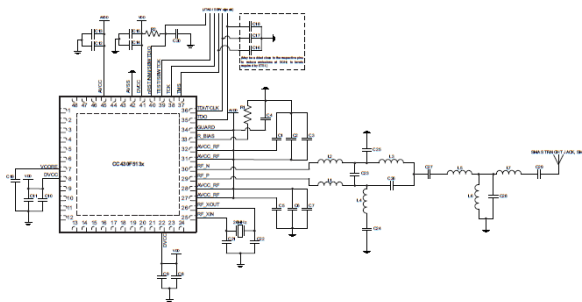


Fig.15 Typical Application Circuit with Antenna Tuning

Figure 15 shows a typical application of the CC430 with tuning for the antenna. The datasheet for the CC430 provides component for a few different frequencies aids in the design.

TESTING THE FINAL DESIGN

Algorithm Tests:

Once the written code was uploaded to the boards, distance tests were performed. This verified that the design was feasible with different code. Three tests were performed indoor and outdoor, similar to the RFStudio tests as seen in Figure 10 and Figure 11.

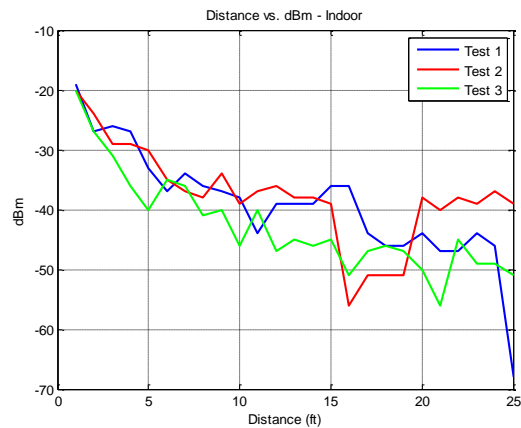


Fig. 16 Indoor Distance Test Results

Figure 16 shows three indoor tests that were performed. Each test follows the same typical slope, this agrees with the indoor RFStudio tests that were executed earlier. Figure 11 shows three outdoor tests. When comparing the RFStudio test to the results of this distance test, the results were not expected. The results are more inconsistent than the indoor distance tests performed, which disagree with the two tests performed using RFStudio. When performing the outdoor distance tests, it was found that when the boards at tested level, the results are much cleaner and more typical. In the case of Figure 17, one board was placed on the ground while the other board was held at about 3 feet from the ground. This can explain the inconsistency of the results.

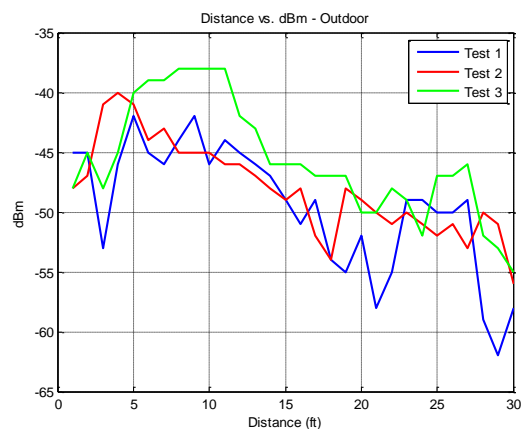


Fig. 17 Outdoor Distance Test Results

Hardware Test:

Before connecting the speaker prototype board to the development kit, the pin programmed to go “high” (sound the speaker) needed to be tested. The code was written to turn on pin 7 every time the speaker needed to beep. When the pin is “high” it should have a 50% duty cycle and a 1 kHz frequency.

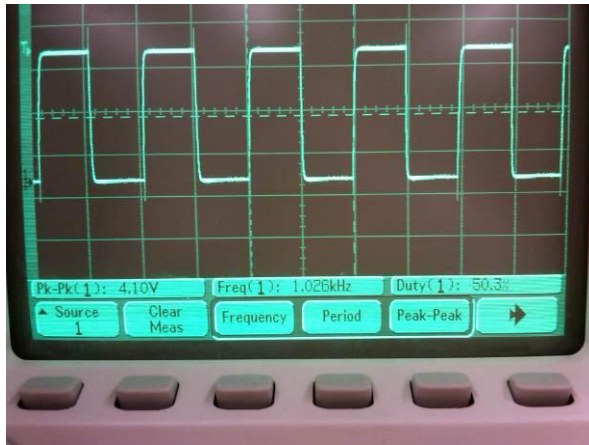


Fig. 18 Oscilloscope Capture of Pin 7

A probe was placed on Pin 7 and the result was captured using an oscilloscope as seen in Figure 18. The frequency is 1.026 kHz and the duty cycle is 50.3%. This verifies that the code is working precisely as designed. The final design was tested and video recorded. The video can be found on the teams website.

HIGHLIGHTS OF FINAL DESIGN

P11252 “Top Cat” is a short range proximity device designed to keep two cats from fighting, but its value is in the way RF is used to approximate distance. The common usage for RF is the transmission of data packets over large distances. There have been many advances in the communication industry that allows for information to be communicated in places and with people never thought possible. These technological advances enable us to show proof of concept and successfully demonstrate our proximity devices.

It is the precision of today’s RF technology which enabled us to use RF within a 30ft range and accurately approximate incremental changes in distance between devices. Utilizing this fact, RSSI was then used as a threshold marker between distances and our short range proximity devices were created, and an appropriate alert system was then added.

In regards to the stimulus used to simulate the alert system to deter the cats; our project gives the devices limitless bounds to whatever stimulus deemed necessary. Using the CC430 processor the stimulus is driven by the output of the processor. This gives us the necessary flexibility for any stimulus to be connected to the processor; which allows for a sound, recording, mechanical motion, or whatever stimulus capable of deterring a cat to be used. In actuality, being able to vary the stimulus gives the device the ability to not just be limited to cats, but be able to deter any animal, person, object, etc. that responds to a stimulus. Figure 19 shows a top view of our “cat” as it was at Imagine RIT.

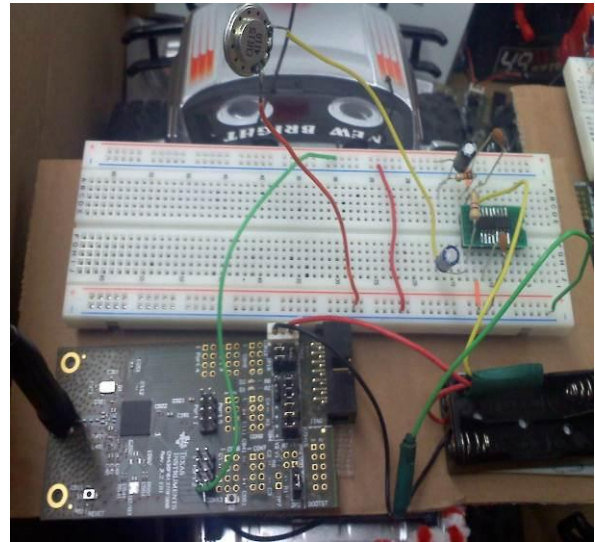


Fig.19 Top View of “Cat”

FUTURE WORK

In future senior design projects, the primary goal should be to design and build two, short-range communication devices that will be placed on cat collars; to safely deter the cats from fighting. Since this project was successful in proving the feasibility of using RF to accurately determine small incremental distances; the next team will focus on the design and construction of the communication devices and the collars. In continuing this project, the primary concerns for the following team will be the design of the antenna and the PCB board to communicate between each device, a collar design that is durable enough to withstand the daily life of a cat, the stimulus that will be used to deter the cats, and finally alternations to the RSSI algorithm that can effectively output a stimulus at a specific thresholds.

In determining the appropriate antenna and board design sufficient testing of different antennas at different frequencies and sizes will need to be done. Above in the *possible fabrication* section, more specifically Figure 12, some consideration factors are illustrated. Those and other potential factors will have to be thoroughly tested because communication between the devices needs to remain accurate and consistent. The precision of the receive signal allows for the short range communication devices to accurately determine distance. It is also recommended that further research is done with the CC430 microprocessor. Its size, weight, and power saving capabilities allows for it to be ideal in being a CPU for the communication devices.

The collar design has to be durable as it will be attached to an outdoor cat. This entails that it has to be able to withstand the natural elements including and

not limited to sunlight, moisture, wind, debris, etc. In addition the electrical elements within the device must be securely placed and tested to work in a quick and abrupt moving environment.

For solutions to stimuli, this will need to be identified with further discussed with customer and tested with the individual cats. One possible solution could be using an ultrasonic frequency that is only audible to the cats. A very successful consumer product “*Cat Stop*” by Contech uses a specific ultrasonic frequency to keep cats away from specific areas. Other potential stimuli could be recorded as .wav files that the cats are conditioned to hear that could be outputted.

Lastly there will be test needed to see what adjustments need to be made to the provided software algorithm. This may include adjustments to the battery saving methods, delay time between transmits and receives, the different threshold etc. The final product must be capable of appropriately approximating the distance of the two cats, at the speeds in which they move in their daily lives. It is necessary to find resolutions to all the above concerns because the customer wants his cat to remain outdoors but not get into anymore altercations.

CONCLUSIONS

The final design successfully approximates distance using RF technology, more specifically using RSSI as an indicator. In a twenty-two week period the project has gone from customer needs to a proof of concept. The proof of concept serves as a valuable start to any other Senior Design group at Rochester Institute of Technology who wishes to take on the hardware development and antenna design to create a final product. This now allows for the project to be continued on to be manufactured and used in a real-world environment.

RF is not widely known as a viable technology that can be used to determine small distances because many common frequencies have the capability to be seen hundreds of yards away for transmitters. Even though this is the case, it is the precision of the RF technology that allows for this technology to be used in short ranges.

As tests have proven the receive signal strength for a hundred packets is moderately precise

with an uncertainty around ± 3 dBm, however the averages are consistent when using the CC1101 radio which is on the CC430 processor. It is this precision in the receive signal strength that allows for thresholds to be directly related to distance. For our purposes a 25ft to 30ft distance is approximately a -45dBm to -50dBm and a 0ft to 5ft distance is approximately -15dBm to -20dBm. This relationship can be considered linear and allows for decibel specific thresholds to be implemented in our RSSI algorithm.

ACKNOWLEDGMENTS

The team would like to express its sincerest gratitude to those who have made invaluable contributions to this project. Many thanks go to our advisor, Mr. George Slack, for his guidance and support. Additionally, the team would like to express thanks to all customer and consultants who provided prompt and relevant assistance, as well as consultative advice when necessary. They are Mr. David Perlman former professor at the Rochester Institute of Technology, Mr. Dorin Patru current professor at the Rochester Institute of Technology and Mr. Bryce Tennant and Mr. Tony Keane for Harris Corporations.

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